CME DEFLECTIONS: A BRIEF REVIEW AND NEW INSIGHTS

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RESUMEN

Investigaciones recientes han demostrado el importante papel que desempeñan las estructuras magnéticas que circundan los eventos de eyecciones coronales de masa (ECM) en su desarrollo inicial y progresión. Los agujeros coronales y los *pseudostreamers* son componentes clave de la corona que contribuyen a la desviación de las trayectorias de las ECM de su trayectoria radial. Por lo tanto, estudios observacionales exhaustivos, junto con interpretaciones teóricas y simulaciones numéricas, son vitales para comprender la evolución temprana de las ECM y determinar con precisión su trayectoria tridimensional en el medio interplanetario. Este enfoque es crucial para reducir errores en la estimación del tiempo de llegada de eventos geoeficaces. En esta concisa revisión, se recopila las investigaciones teóricas, numéricas y observacionales que han proporcionado información sobre los factores que influyen en la deflexión de las ECM fuera de su típica trayectoria radial.

ABSTRACT

Recent research has demonstrated the significant role played by magnetic structures surrounding coronal mass ejection (CME) events in their initial development and progression. Coronal holes and pseudostreamers are key components of the corona that contribute to the deviation of CME trajectories from their radial path. Therefore, comprehensive observational studies, coupled with theoretical interpretations and numerical simulations, are vital in understanding the early evolution of CMEs and accurately determining their three-dimensional trajectory in the interplanetary medium. This approach is crucial for reducing errors in estimating the arrival time of geoeffective events. In this concise review, it is compiled from the theoretical, numerical, and observational investigations that have provided insights into the factors influencing CME deflection away from their typical radial trajectory.

Key Words: Sun — coronal mass ejections — magnetic fields

1. GENERAL

The understanding of coronal mass ejections (CMEs) propagation is critical for space weather forecasting, with factors such as deflection of CME playing significant roles.

Observational research has revealed interesting patterns regarding CME deflection. During periods of minimal solar activity, CMEs consistently deflect toward lower latitudes, where the heliospheric current sheet -a region of minimal magnetic energy- is located (Cremades & Bothmer 2004). However, in high-activity periods, this trend is lost.

Considering other structures with regions of low magnetic energy -as pseudostreamers (PSs)- suggests that the magnetic environment surrounding the eruption region can influence the deflection of CMEs within the first few solar radii (Liewer et al. 2015). Analyzing the magnetic forces generated by the background corona, Shen et al. (2011) show the magnetic pressure play pivotal rol.

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On the other hand, certain magnetic structures, like coronal holes (CHs) and active regions (ARs), possess the ability to repel CMEs. This deviation occurs due to the strong magnetic field topology of the AR and the open flow area of an adjacent CH (Möstl et al. 2015).

However, there are observational studies that show that it is difficult to predict the trajectory of a CME when there are multiple magnetic structures surrounding the source of the CME (Jiang et al. 2007; Sieyra et al. 2020).

Therefore, in order to characterize general behaviors, it is essential to comprehend the root causes of deviations. Given the intricacies of the phenomena, it is necessary to consider various factors and mechanisms that contribute to these deflections.

2. REPULSORS AND ATTRACTORS

Observational studies have examined how CHs deflect CMEs from their radial trajectory. Cremades et al. (2006), analyzing a large number of events, showed that CMEs systematically move away from CHs. From their analysis, they demonstrated the existence of a force that causes this divergence, which is linearly dependent on the area of the CH and inversely proportional to the distance between the CME source and the hole. Three years later, Gopalswamy et al. (2009), additionally showed that this force is linearly dependent on the magnetic field of the CH. In this way, CHs are considered as magnetic walls, acting as repulsors that push CMEs away.

On the other hand, pseudostreamers act as attractors of CMEs. Yang et al. (2015) show in observational studies that the CME approaches the region of low magnetic energy, and an imbalance in magnetic pressure occurs due to magnetic reconnection, deflecting the CME.

3. MODEL AND NUMERICAL STUDIES

Observations in white light reveal that CMEs are composed of a leading edge, a dark cavity, and a bright core. This structure corresponds to a flux rope (FR) model, where a helical magnetic field can support and expel material from the corona into the interplanetary medium through coronal mass ejection. Using the catastrophe model proposed by Forbes (1990), the dynamics of this FR can be resolved by solving the MHD equations through numerical simulations.

In this way, in Sahade et al. (2020, 2021), the deflection of a FR in the presence of a CH was analyzed in isolation. We found that the combination of both magnetic structures creates a region of minimum magnetic energy where the CME is deflected, and then the deflection is channeled by the magnetic field lines of the CH. We numerically demonstrated that the deflection increases when the magnetic field of the CH is stronger, when the distance between the CH and FR is smaller, and when the area of the CH is larger, consistent with the aforementioned observational studies. We also showed that the CH can act as an attractor. If the polarity of the FR is anti-aligned with respect to the CH, an approach to the CH occurs first, and then, the guidance of the CH magnetic field lines leads to the motion away from the CH.

On the other hand, in Sahade et al. (2022), we analyzed how a PS influences the deflection of a FR. In this case, since the PS intrinsically possesses a region of minimum magnetic energy at its cusp -null point (NP)-, the presence of the FR creates another NP where the rope initially moves toward. However, we demonstrated that depending on the intensity of the magnetic field of the PS, the FR can move toward the NP of the PS, it can move away from this NP, or it may not eject.

Using this knowledge, in Sahade et al. (2023) we explain the anomalous trajectory of the famous Cartwheel Event, the CME suffers a double deflection due to the combination of a neighboring PS and CH.

4. FINAL COMMENTS

These investigations highlight that the crucial factor for the initial deflection is the presence of regions of low magnetic energy. Subsequent alterations in the trajectory of the CME are attributed to the channeling of the ambient magnetic field. The anomalies observed in specific cases are further elucidated by considering the relative magnetic polarity between the CME source and the adjacent magnetic structure.

Nevertheless, observational studies show that within a dynamic and magnetically intricate coronal environment, there are additional factors to take into account. These include magnetic reconnections that modify the magnetic topology, the inertia or the twisting within the CME, and various other dynamical effects. Understanding these complexities is essential for unraveling the intricate dynamics of CME trajectories.

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